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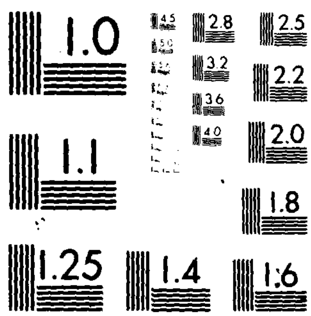

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AN ASSESSMENT OF TECHNICAL FACTORS INFLUENCING THE POTENTIAL USE OF RPVs FOR MINEFIELD DETECTION

Y. MORITA and H. McKENNEY
Radar and Optics Division

JULY 1980

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An assessment is made of the use of television and FLIR sensors carried on RPVs as remote minefield detection systems, based on four major scenarios for Soviet mine warfare operations involving the use of TM-46 metallic and PM-60 plastic anti-vehicular mines. The RPV system minefield detection capability, response time and search rate are functions of the sensor resolution, field of view and sensitivity capabilities; the obscuration

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20. ABSTRACT (Continued)

due to vegetation, atmospheric attenuation, terrain and weather; the radiance contrast existing between mines and background; the airborne platform characteristics; data link characteristics; the man/machine interface; and command, control and communication system characteristics. These factors are considered in this study to initially define the minefield detection capability of currently planned RPVs, to indicate areas where additional data is needed to provide a better definition of RPV minefield detection capabilities and to indicate parameters for an improved next generation sensor system.

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PREFACE

The objective of the minefield detection project is to determine the effectiveness of remote sensing systems and other methods of detecting and identifying mines, minefields, minelaying equipment, or minelaying operations, and to recommend continuing effort on the most promising methods.

Work under the project concerned with each of the concepts to be investigated is being performed in a sequence of four major tasks: (1) identification and screening of promising techniques; (2) preliminary systems analysis and definition of experimental or other data acquisition systems; (3) acquisition of critical data through experiment, literature survey, or access to SCI; and (4) evaluation of conceptual systems for technical performance and military usefulness.

This is one of a series of reports documenting technical effort and results achieved during the project. This report covers work performed under Task 2, Preliminary Systems Analysis of Candidate Systems.

Dr. J. Roland Gonano monitored the program for MERADCOM, Mr. Henry McKenney was the ERIM Program Manager, and Mr. Yuji Morita performed the analysis.

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1 INTRODUCTION

Previous studies and experiments have led to the conclusion that remote detection of Soviet minefields is possible provided that they are observed from above. This conclusion raises the question as to whether the currently planned RPV system can detect minefields. This preliminary study addresses this question and delineates the flight regimes where detection should be possible, considers factors affecting operational usefulness, and suggests parameters for a next generation sensor which will enhance the minefield detection capability of the RPV system. A general description of the RPV, its capabilities and operational and organizational concept are given by Refs. [1] and [2], which are used as a basis for discussion in this report.

Four major scenarios for Soviet mine warfare operations have been considered in this study. These scenarios result in the use of mines for (1) protecting the most exposed flank during meeting engagement; (2) protecting shoulders during breakthrough; (3) blocking the movement of reinforcements, and (4) supporting a prepared defense. The first three scenarios are representative of Soviet offensive operations and are characterized as hasty operations with mines being in place a relatively short time. These scenarios have the following technical implications. Both surface and buried minefields comprised of either plastic or metallic mines must be detected. The sensor/carrier vehicle combination ideally should have quick reaction time, and a day/night, all-weather capability. Rapid acquisition and transmission of information to ensure maximum usability to the local unit commander is required. Finally, the sensor/carrier vehicle combination must not be unduly vulnerable to enemy actions.

The RPV system minefield detection capability, response time and search rate are functions of the sensor resolution, field of view and sensitivity capabilities; the obscuration due to vegetation, atmospheric attenuation, terrain and weather; the radiance contrast existing between mines and background; the airborne platform characteristics; data link characteristics; the man/machine interface; and command, control and communication system characteristics. These factors are considered in this study to initially define the minefield detection capability of currently planned RPVs, to indicate areas where additional data is needed to provide a better definition of RPV minefield detection capabilities and to indicate parameters for an improved next generation sensor system.

2
GENERAL CONSIDERATIONS

The relationship of the four major scenarios to the forward edge of the battle area (FEBA) is indicated in Figure 1. Flight times to potential minefield sites within the division area associated with scenarios 2 and 3 are not likely to exceed 15 min. Flight times to potential minefield sites associated with scenarios 1 and 4 are not likely to exceed 30 minutes.

If we assume that it is possible to locate the RPV remote ground terminal so that the masking effect of the terrain and vegetation features on the line-of-sight does not exceed 50 m altitude per kilometer range from the remote ground terminal, then the minimum altitude above ground line permitted for minefields associated with scenarios 2 and 3 is well under 1000 m. and for scenarios 1 and 4 under 2500 m.

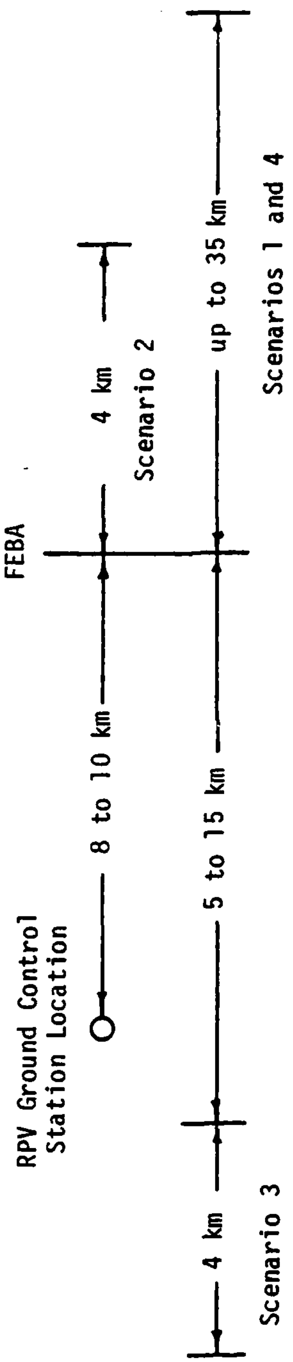


Figure 1. Minefield Relationship to FEBA

3
MINE AND MINEFIELD CHARACTERISTICS

The four major scenarios for Soviet mine warfare operations involve the use of the Soviet TM-46 metallic anti-vehicular mine and the PM60 plastic anti-vehicular mine. These mines are typically installed in rows with spacing between mines in a row averaging from 4.0 to 5.5 m apart. The rows are spaced from 25 to 50 m apart.

The RPV sensors depend on contrast between the targets and the background to detect the targets. To date, limited tests have been conducted to establish a preliminary basis for predicting the contrast to be expected from a Soviet minefield with respect to a typical background.

Although the estimates and the conclusions are drawn on highly limited data so that high confidence cannot be placed on them, sufficient confidence can be placed in the results to indicate that minefield detection is possible under proper circumstances. Additional tests should be run to achieve more confidence.

Tests were performed at MERADCOM to establish the apparent temperature contrast between mines and the background over a diurnal cycle. The conditions under which the tests were run and the results are given in Appendix I [3]. The results given in the appendix have been replotted in Figures 2 and 3 as apparent temperature differences between mines and background to indicate the contrast magnitudes.

Detectors typically have sensitivities on the order of a few tenths of a degree. Assuming that the detectivity threshold is typically 0.5°C then both figures indicate that for all four mines considered, the apparent temperature difference between mines and background exceeds the ±0.5° contrast required a high percentage of the time. These percentages are plotted as the high values in Figure 4. If we assume a detectivity threshold of 2.0°C then the low values given in Figure 4 apply.

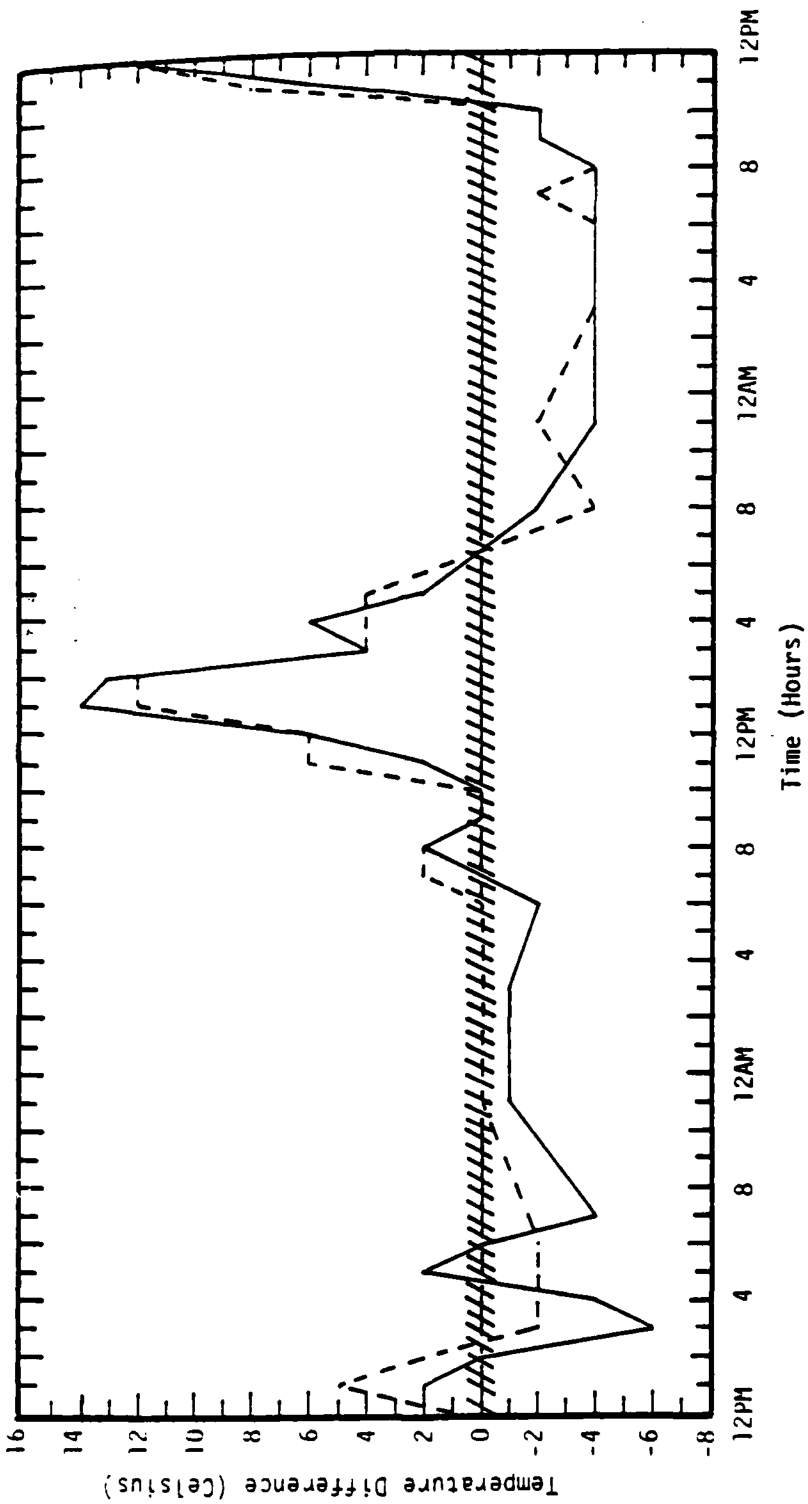


Figure 2. Mine/Background Temperature Contrast

———— TM-46
- - - - - PM-60
////////// ±0.5° Contrast

The solid lines represent both mine contrasts where the lines coincide.

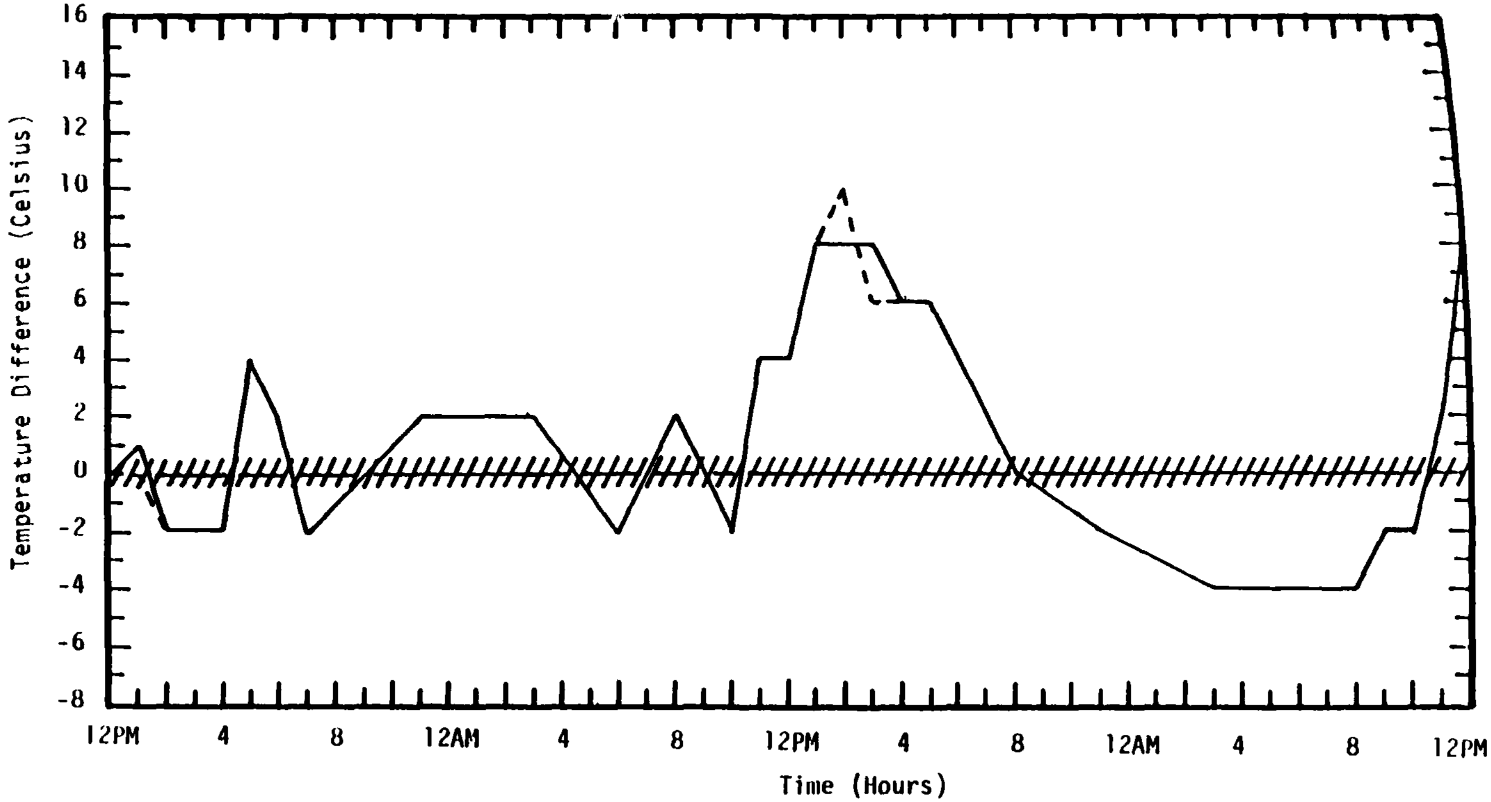


Figure 3. M-15 Mine/Background Temperature Contrast

- - - - - - - - -	First M-15
---------	Second M-15
/////////	±0.5° Contrast

The solid lines represent both mine contrasts where the lines coincide.

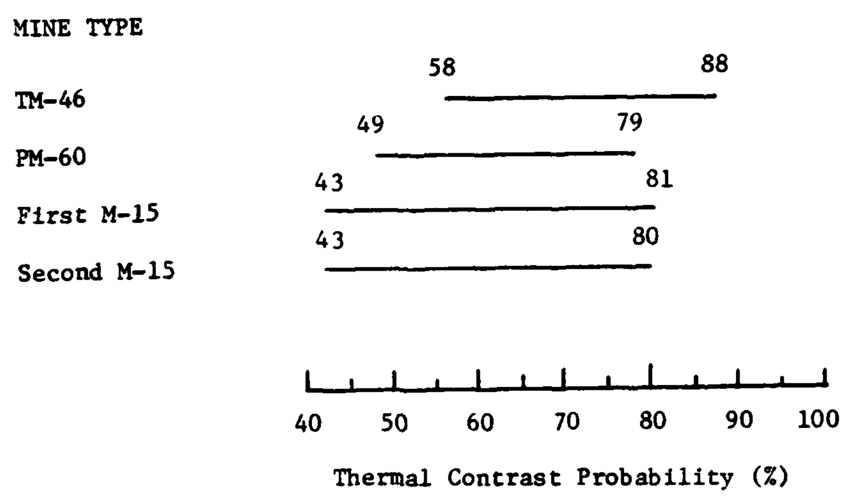


Figure 4. Range of Thermal Contrast Probabilities for Detection Thresholds of 2.0°C. and 0.5°C.

Paints used on mines are chosen to have reflectance characteristics similar to that of vegetation in the visible portion of the spectrum. The poor contrast between mines and a background consisting of vegetation makes the task of detecting mines difficult under these conditions. On the other hand, contrast may be enhanced on surfaces where specular returns are possible.

It is expected that television systems will be able to detect mines under contrast conditions similar to those where photographic systems are able to detect mines. The performance of television systems may be poorer than the performance of a passive infrared system operating in the 10 to 14 μm region since the sparse data that exists suggests that the atmospheric extinction coefficient at the visible wavelengths can be as much as an order of magnitude higher for altitudes up to 100 m under conditions of ground fog and haze [4]. There is little data on variations in extinction coefficients as a function of altitude; collection of more data appears to be warranted.

4
RPV SENSOR CONSIDERATIONS

Experience has shown and Array I tests have confirmed that targets to be detected must be covered by at least two increments of a sensor's resolution element. Figure 5 illustrates the locus of points (a circle) on or within which an RPV must fly if a given number of resolution elements (or lines) are to be maintained on a mine. Note that on a slope, the horizontal component of swath width is narrower than on level ground. This effect is not serious as far as search time is concerned in that even for very steep gradients, e.g., 60%, the horizontal component is still over 85% of the width on level ground (Figure 6). The width change is negligible on less steep slopes on which minefields can be expected.

The television camera presently planned for use on the RPV is to have a capability to image three fields of view (FOVs). These are 2.7°, 7.2°, and 20° diagonal FOVs respectively. It can be shown that the swath width attainable is equal to

$$2s = 2h \tan \phi = \frac{2dm \sin \phi \cos \phi}{n2\phi}$$

where h = RPV altitude,

ϕ = half the field of view,

n = the number of resolution lines desired on a target,

m = the total number of resolution lines

d = the mine diameter

For small ϕ, cos ϕ is approximately one and sin ϕ is approximately ϕ. The equation may be simplified to

$$2s = d \frac{m}{n}$$

The swath width is independent of the FOV, directly proportional to the number of lines in the television system and inversely proportional to the number of resolution lines desired on the target. The

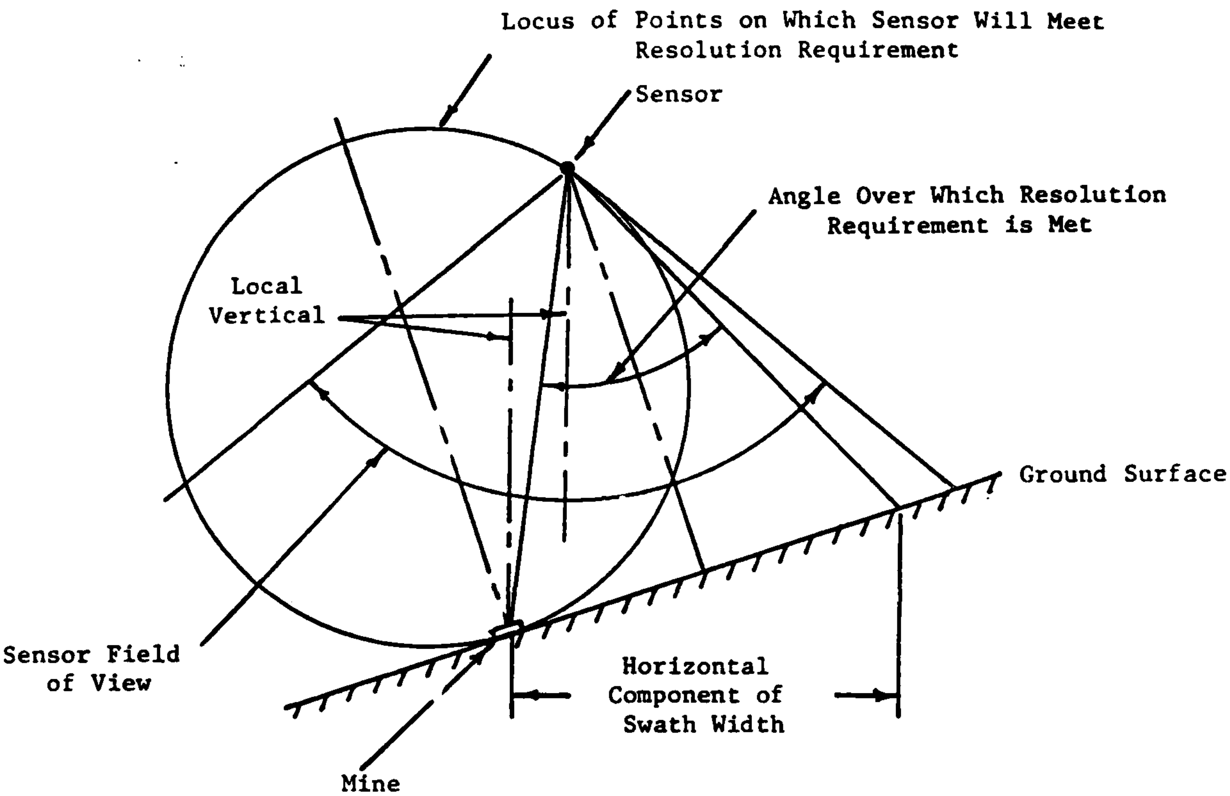


Figure 5. Geometry for Determining Horizontal Component of Swath Width on a Slope

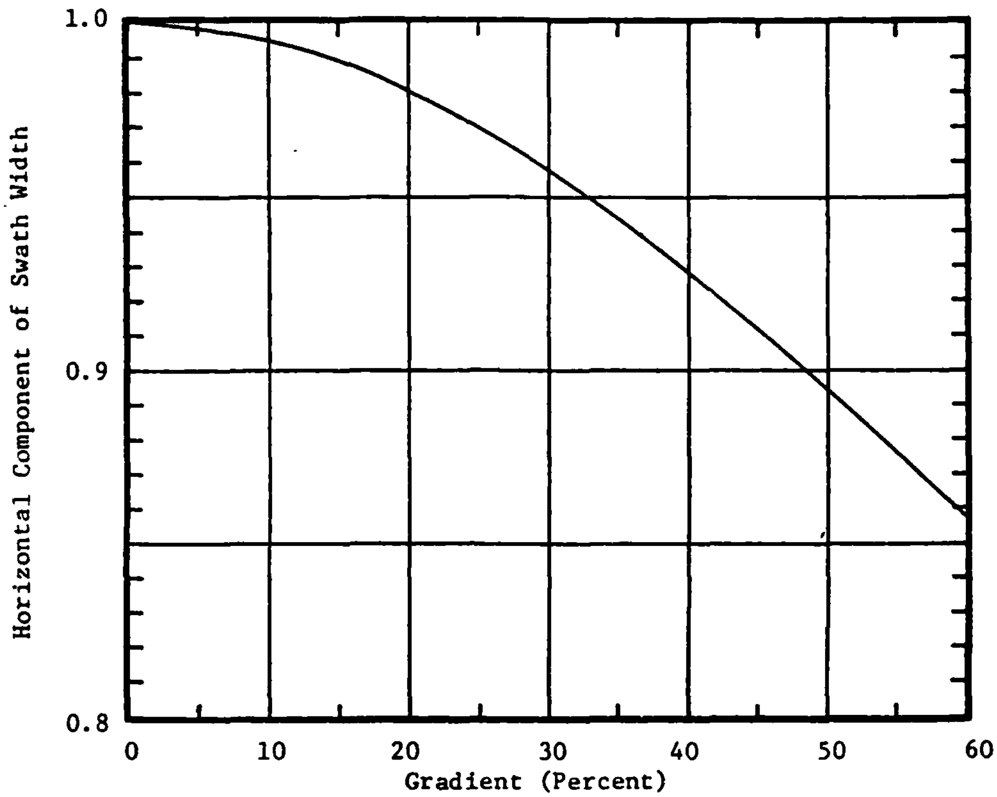


Figure 6. Effect of Gradient on Swath Width

swath width and the number of lines on a mine for a 350 line system* is illustrated in Figure 7 for the three FOVs. The nominal swath width is approximately 70 m for two lines on a mine. For a given FOV, the swath width becomes narrower as RPV altitude is reduced (Figure 7). Simultaneously, the number of lines on a mine increases.

Note that the narrowest FOV permits one to fly higher than the wider FOVs. This is advantageous from the standpoint of maintaining communications and from the standpoint of lessening mine obscuration by vegetation. With a 2.7° field of view, the requirement for two lines on a mine limits maximum altitude above ground to approximately 1860 m. On the other hand, limitations due to cloud ceilings increase with increasing sensor altitude.

The individual TV sensor elements integrate target/background signal from frame to frame. Since RPV motion during the frame interval (nominally about 1 m) exceeds the dimension of the individual mine (0.3 m), ability to discern minefields is adversely affected. Dependent on design approach chosen, this situation may also occur for the forward-looking infrared system (FLIR). This effect and approaches to minimize it are discussed in more detail under RPV characteristics.

Vidicon tubes with glass windows have a spectral response characteristic whose peaks occur between 0.4 to 0.5 μm or in the blue to green portion of the spectrum. The response is down to about half the maximum in the yellow portion of the spectrum and is not more than 10% in the near infrared. In contrast, the human eye's response peaks in the yellow portion of the spectrum. If quartz windows are used in the vidicons, their useful sensitivity can be extended into the ultraviolet region. Silicon vidicons have broad high reponse

*Minimum requirement of EIA Standard FS330, dated November 1966.

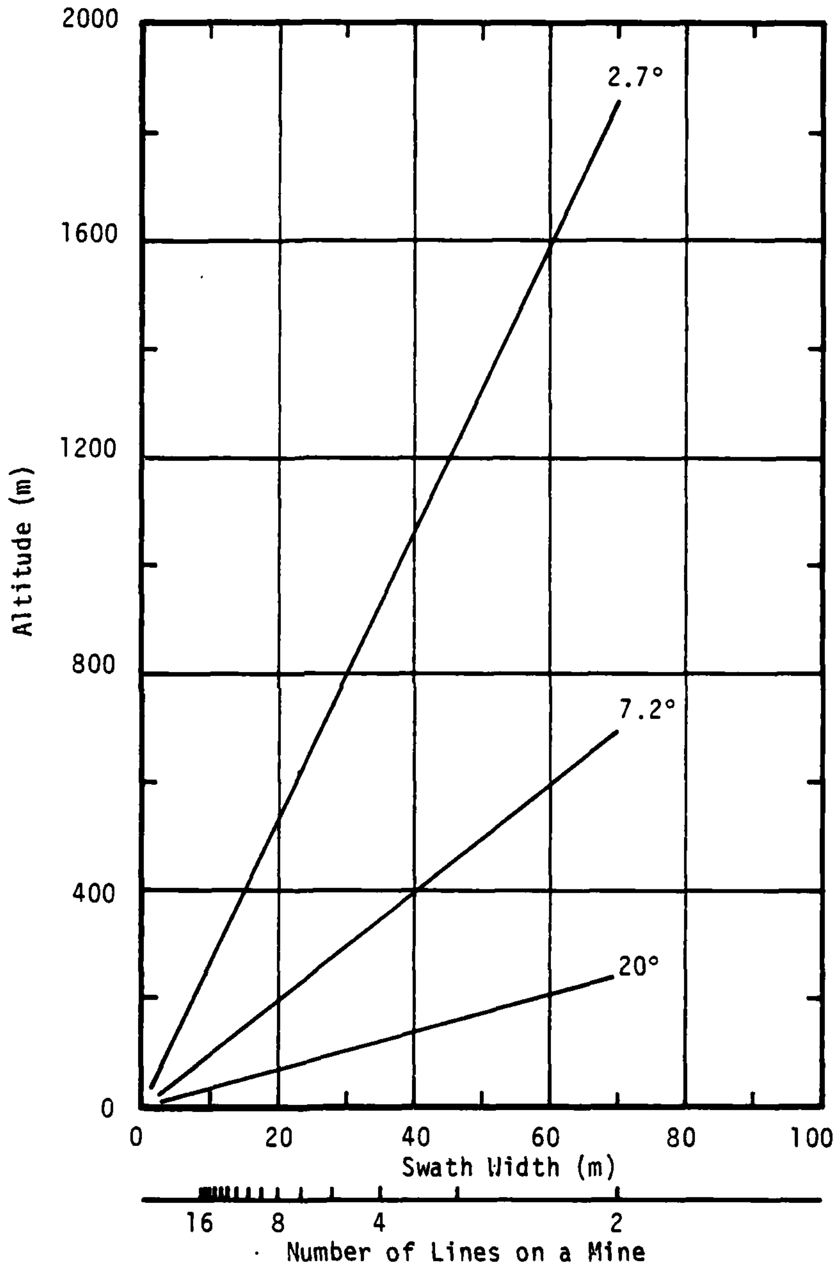


Figure 7. Diagonal Field of View Versus Altitude and Swath Width

Mine Diameter = 0.3 m

from about 0.4 to 1.0 μm [5]. The response characteristics of these several types of vidicons should be compared to the spectral reflectance characteristics of mines and backgrounds to determine if any of these tube types offer an advantage over the others in detecting surface laid mines.

One of two developmental FLIRs is to be chosen for eventual use with the RPV. The specifications for either of these two units are not yet available to ERIM. Consequently, for the purposes of this report, a FLIR system is postulated. This system is able to point straight down, have the same diagonal FOVs as the television sensor, namely, 20°, 7.2°, and 2.7° with an aspect ratio of 4 to 3, and to have 0.10 mrad resolution in the vertical dimension of the 2.7° FOV. This is tantamount to having a linear array of 280 detectors in the vertical dimension with sweep in the horizontal dimension. The resolution in the horizontal dimension is assumed to be the same as in the vertical dimension. Since the number of detectors is fixed, the resolution decreases as the FOV increases.

Equations similar to those used for calculating the television sensor altitude and swath width for a minimum of two lines on a mine can be used to calculate the same quantities for the FLIR. These values along with the resolution capability are listed in Table 1. As for the television case, swath width remains essentially invariant because the resolution decreases as the FOV increases. Similarly, sensor altitude can be increased as the FOV increases. Again as for the television case, in good weather, the narrowest FOV should be used in order to minimize line of sight obscuration both for the sensor and the data link.

It is of interest to note that the swath width for the postulated FLIR is only 0.8 the swath width for the television system. This is so because the FLIR has a resolution which is 25 percent poorer than the television system. For the 2.7° FOV for both systems the resolution is 0.1 mrad for the FLIR and 0.08 mrad for the television

TABLE 1
FLIR ALTITUDE AND SWATH WIDTH

Diagonal FOV (degrees)	Resolution (mrad)	Sensor Altitude (meters)	Swath Width (meters)
20	0.75	197	55
7.2	0.27	556	56
2.7	0.10	1485	56

system. If a resolution of 0.08 mrad is assumed for the FLIR with 353 detectors in place of 280 detectors for the 0.1 mrad system, both the FLIR and television systems would have a swath width of 70 m.

5
OBSCURATIONAL FACTORS

The major obscuration factors for the RPV mission payload system affecting sensory access are weather, terrain, vegetation and atmospheric attenuation.

5.1 WEATHER

Figure 8 illustrates the percentage of time cloud ceilings are below a given altitude in two areas of West Germany. At 1000 m altitude, cloud cover can be expected about 50% of the time at Bayreuth and 40% at Düsseldorf [6]. This suggests the use of the wider fields of view together with flight at the corresponding lower altitudes when cloud ceilings obscure visibility at the higher altitudes.

5.2 TERRAIN

The effect of sloping terrain was illustrated in Figures 5 and 6 and discussed in the accompanying text. Generally anti-vehicular minefields are to be expected in trafficable areas (slopes of 30° or less). Consequently, reduction in swath width will be minimal. Since the viewing angle of the RPV mission payload sensors can be adjusted over the lower hemisphere, a partial compensation for effects of terrain slope on sensor performance is available to the RPV operator or sensor operator.

5.3 VEGETATION

The effect of vegetation in obscuring sensory access to mines can be important. The geometry of vegetational obscuration of a mine is shown in Figure 9. The mine is assumed to be on a flat terrain. The sensor carrying air vehicle is assumed to be flying in a straight line with a level attitude and the sensor is assumed to be

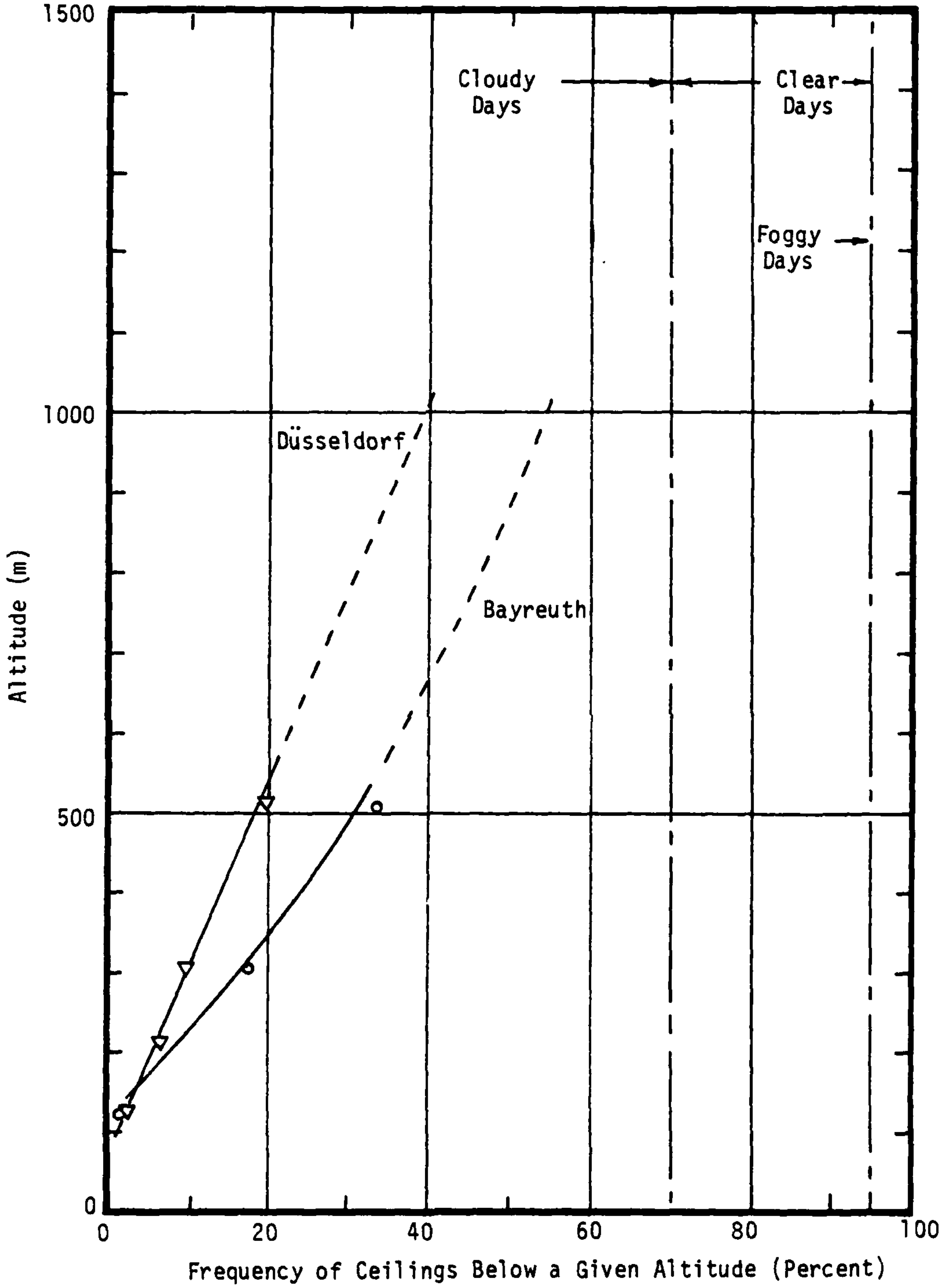


Figure 8. Cloud Ceilings Below a Given Altitude
Düsseldorf, Zone 5(a); Bayreuth, Zone 7(c).

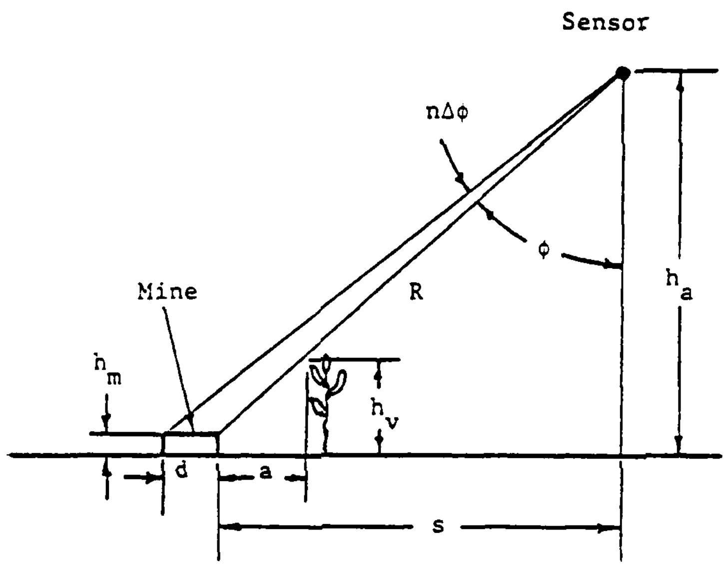


Figure 9. Sensor, Mine and Vegetation Geometry

stabilized. The vegetation is assumed to be sufficiently dense as to completely obscure a mine if interposed between the mine and the sensor. This assumption for vegetation density should lead to conservative results since foliage density will vary considerably according to the types of plants and seasonal changes. The numbers arrived at should be viewed as boundary values useful in choosing operational conditions of flight.

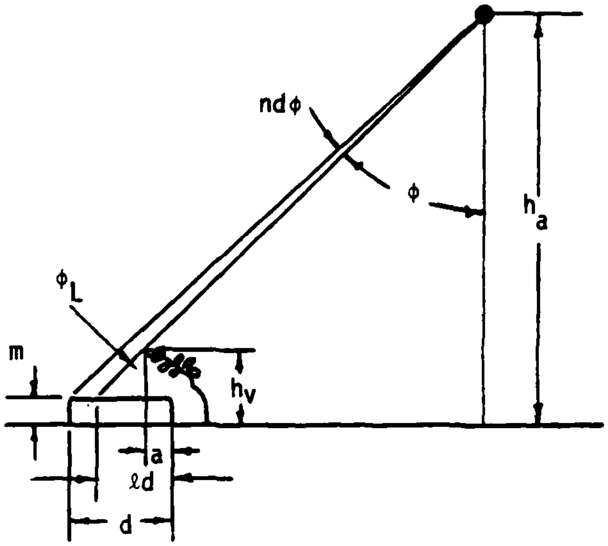
Vegetation effects on permissible flight paths can be determined by calculating the limiting half scan angle ϕ_L from the vegetation-mine geometry. The line of sight is assumed to be completely blocked by vegetation. The angle can be expressed by

$$\phi_L = \tan^{-1} [(\ell d + a)/(h_v - h_m)]$$

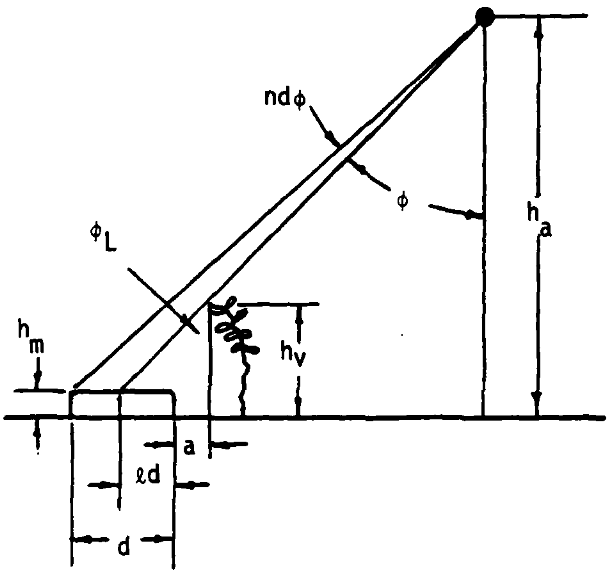
where ℓ is that fraction of the mine diameter, d, obscured by the vegetation and a is the projection of the distance measured from the mine edge to the point on the plant which just blocks the line of sight, h_v is the plant height and h_m is the mine height. If a is negative, a portion of the plant overhangs the mine (Figure 10(a)). For positive a, there is no overhang (Figure 10(b)). Which situation exists depends on plant type and number of plants in a mine's vicinity. The fraction ℓ can take on any value between 0 and 1. If zero, no overhang can exist and a cannot take on negative values. If one, overhang is complete (or the vegetation is infinitely tall, an impossible condition) and a is equal to -d. For any other value of ℓ between 0 and 1, a can be any positive value or any negative value which is not less than $-\ell$. For example, if ℓ is 0.5, the equation for ϕ_L is

$$\phi_L = \tan^{-1} [(\frac{d}{2} + a)/(h_v - h_m)]$$

$$-\frac{d}{2} \quad a < \infty$$



(a) a is negative and the plant overhangs the mine



(b) a is positive and there is spacing between plant and mine

Figure 10. Geometry for the Overhang Case

Specific cases of vegetation effects are plotted in Figure 11 for three different values of resolution and for $\ell = 0$. Spacing a between vegetation and mine is 0.05 m (2 inches). The vegetation limiting radials apply to all three resolution circles. Vegetation with a height of one ft (0.3 m) limits achievable swath width to approximately two thirds of the maximum achievable under ideal conditions. This figure clearly illustrates that sensors should be flown somewhere in the upper half of the permissible locus, preferably as close to mid-altitude as possible (with respect to the theoretical maximum) in order to maximize swath width. The effect of variations in spacing between mine and vegetation is illustrated in Figures 12 and 13. Altitudes and swath widths in Figure 12 are normalized with respect to the locus circle diameter given by $d/n\Delta\phi$. If the spacing between mine and vegetation is reasonably large, as in cases c and d, the achievable swath width is respectable even for vegetation as tall as 0.5 to 0.6 m. These figures underline the importance of at least estimating the nature of plant cover at suspected minefield locations so that reasonable missions can be flown.

In many instances, plants will overhang a mine so that only portions of that mine can be seen. In terms of the limiting angle equation, a takes on negative values. How much of a mine is observable from a given aspect angle is a function of many variables including plant type, spacing, growth season, etc. Any meaningful data must be gathered in the field and the data treated on a statistical basis. Nevertheless, it is instructive to calculate the effects of overhang on the scanner FOV, altitude, and swath width using the geometry of Figure 10a. That fraction of the mine diameter which is not observable is labeled ℓd. Note that that portion of the mine which is observable may include a portion which is beneath vegetation overhang on the side opposite the viewing direction. This may not be a valid assumption for passive sensors but the conclusions which can be drawn from the assumed model are sufficiently realistic to

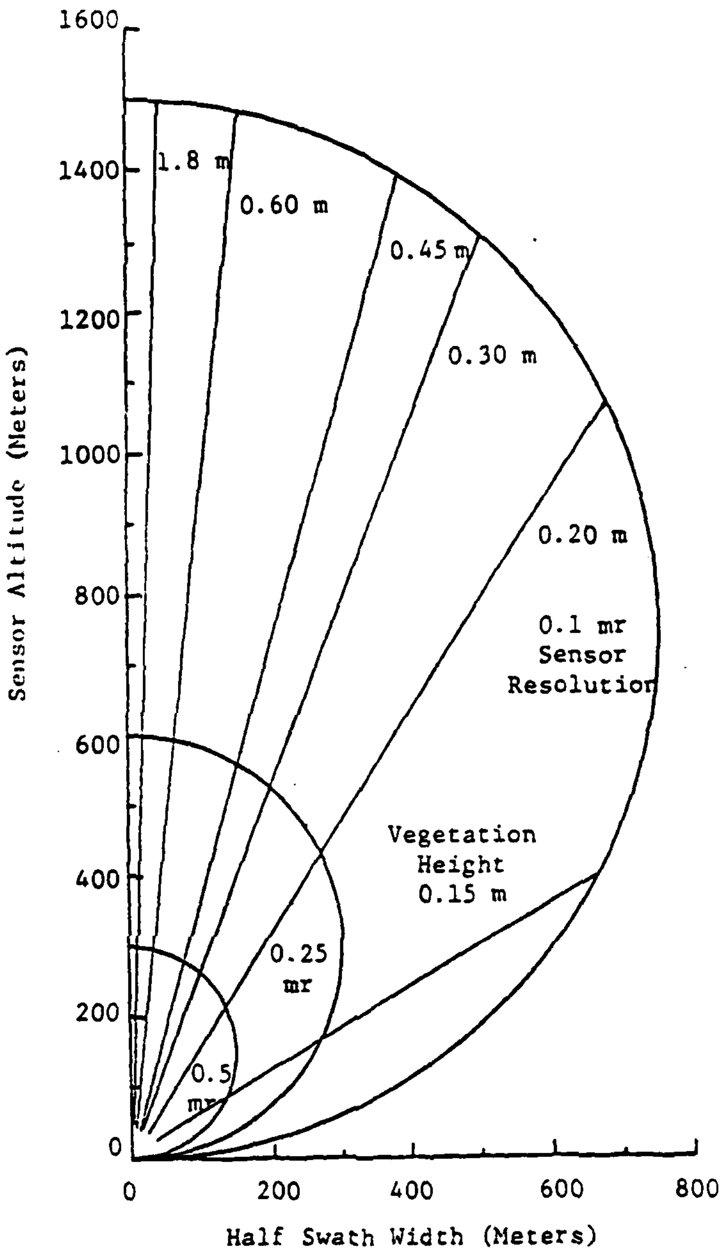


Figure 11. Effects of Vegetation Height and Sensor Resolution on Sensor Altitude and Swath Width. Spacing Between Mine and Vegetation, 0.05 m.

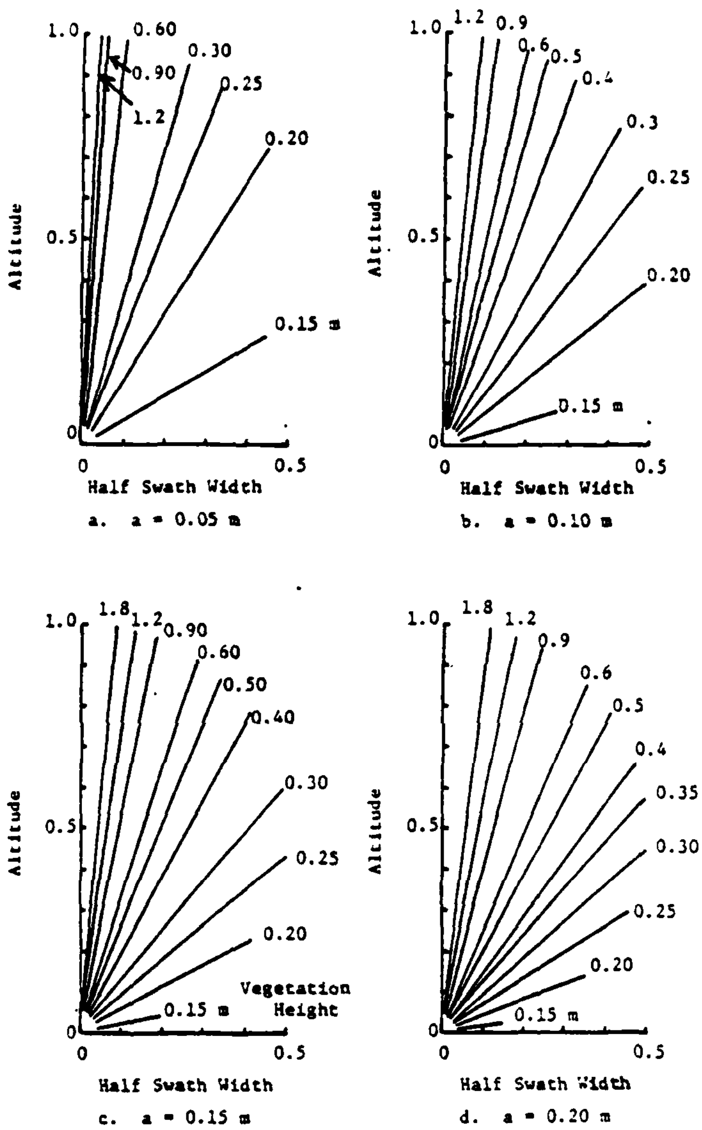


Figure 12. Vegetation Effects on Altitude and Swath Width as a Function of "a"

Altitudes and swath widths are normalized with respect to $d/n\Delta\phi$. "a" is the spacing between mine side and vegetation.

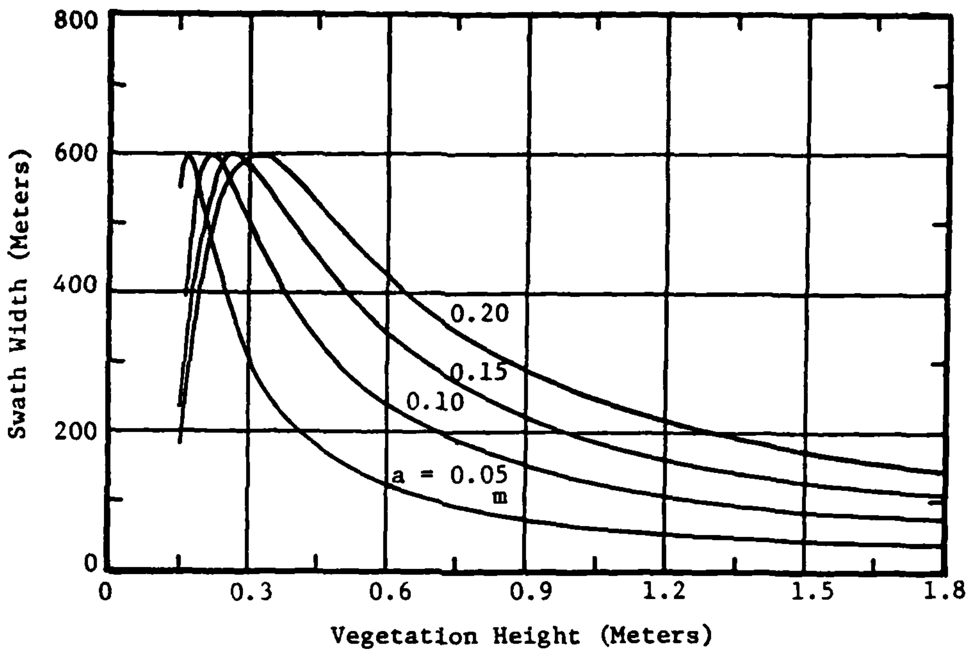


Figure 13. Vegetation Height and Spacing Effects on Swath Width

a is the distance between mine and vegetation. Two lines on the mine and sensor resolution of 0.25 mrad. Scan angles greater than 45° result in swath widths narrower than the maximum width (part of curves to the left of the peaks) and scan angles less than 45° result again in swath width narrower than the maximum width (part of curves to the right of the peaks).

delineate reasonable operational limits. Only field data can provide more realistic information.

Figure 14 illustrates how overhang or spacing between vegetation and a mine affect the limiting scan angle. If vegetation overhangs a mine, the scan angle is limited to small values. For vegetation even as short as 0.3 m, the useful half scan angle is less than 10 deg. if either one quarter (ℓ = 0.75) or three quarters (ℓ = 0.25) of the mine diameter is to be observable. For the former case, the overhang can be as much as 0.225 m. In the latter case, where more of the mine must be seen, the overhang can be maximum of 0.075 m. In both these cases, the limiting half scan angle is zero. As expected, the limiting scan angle increases as overhang decreases and spacing between mine and vegetation increases. Figure 14b illustrates an intermediate case in which half a mine (ℓ = 0.5d) must be observable. It is clear from these figures that overhang severely bounds the scan angles over which mines can be detected; hence, swath widths will also be decreased substantially with swath width given by

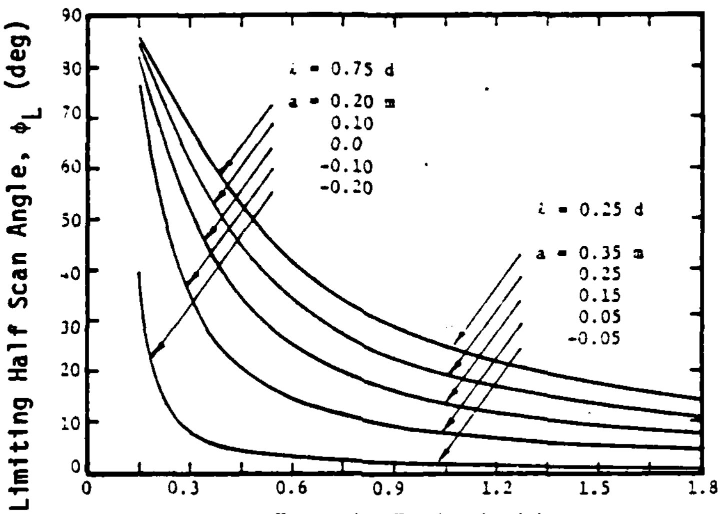
$$2s = \frac{\left(1 - \frac{\ell}{d}\right) d \sin 2\phi}{n \Delta\phi}$$

for ϕ less than ϕ_L.

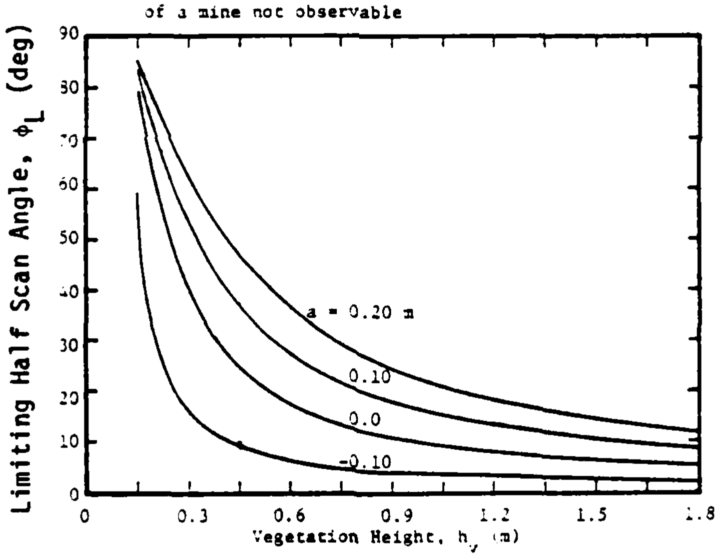
5.4 ATMOSPHERIC OBSCURATION

Scattering and absorption are two mechanisms which affect the transfer of radiation in the Earth's atmosphere. Both molecules and aerosols are involved in these processes. High concentrations of aerosols and gasses close to the ground can be expected on a battlefield, concentrations caused by dust churned up by vehicles, exhaust gasses, gun smoke, smoke intentionally emitted for screening purposes, etc.

How environmental, seasonal and diurnal conditions affect transmittance has been studied and modeled extensively [4]. Many



a. One quarter (ℓ = 0.25 d) and three quarters (ℓ = 0.75 d) of a mine not observable



b. One-Half (ℓ = 0.5 d) of a mine not observable

Figure 14. Effect of Vegetation Spacing on Limiting Scan Angle.
Negative values of a refer to overhang.

measurements have been made as well, particularly along horizontal paths. Apparently, little data have been gathered on transmissivity characteristics along vertical paths, particularly at low altitudes. What data exists indicates that high extinction coefficients can be expected at those altitudes at which mine and minefield detection sensors would be flown. These coefficients vary widely depending on the weather and other environmental conditions.

How atmospheric transmissivity affects particular minefield detection sensors should be modeled and validated by experimental results.

6
RPV CHARACTERISTICS

The major characteristics of the RPV which affect minefield detection performance are delineated and discussed herein. Endurance; range; altitude limits; minimum, cruising and maximum speeds; degree of stabilization available for sensors; payload; vulnerability; sortie rate and field of unobstructed view available to the sensor package are among the important RPV parameters affecting minefield detection performance.

The range measurements from FEBA associated with minefield detection are as illustrated in Figure 1. The RPV range capabilities substantially exceed these requirements for a typical brigade or division front (the divisional RPV allocation consists of four sections).

Similarly RPV endurance is quite adequate for detailed examination of designated areas and for conducting general search patterns in the areas where enemy doctrine indicates minefields will be used. This subject is discussed in more detail in Section 11.

The RPV service ceiling of at least 3600 meters greatly exceeds the maximum altitude at which current or planned sensors can resolve Soviet mines and minefields. Further, reference to Figure 8 indicates the general desirability of RPV flight at altitudes considerably lower than 3600 m in order to minimize effects of sensor obscuration by clouds.

The preliminary examination has been made of the effects of RPV speed on sensor and man/machine interface performance. The magnitude and range of RPV speed, 90 km/h minimum, 180 km/h maximum and 120 km/h typical cruise, together with target resolution and look angle requirements impose operating mode restraints on the TV sensor and they may impose similar restraints on the FLIR sensor dependent on

particular FLIR design. Assuming spatially stabilized sensor viewing from a near-nadir position with a frame rate of 30 per sec, then RPV motion represents a displacement potentially varying from 0.83 m per frame to 1.67 m per frame. Since the TV sensor elements integrate signals from frame to frame the signal from the mine (0.3 m diameter) will be integrated with signal from adjacent background (0.83 to 1.67 m in length). To avoid this effect the TV sensor can be put in the correlation tracker mode and reset periodically in accordance with RPV speed so that complete coverage in the flight direction is obtained. Contacts have been made with the RPV mission payload subcontractor and his preliminary assessments indicate the feasibility of this "snapshot" mode of operation. This "snapshot" mode can also be used with a FLIR. The effect of continuous motion as described or a "snapshot" presentation on the ability of the RPV display operator to detect Soviet mines or minefields is uncertain at present. It is recommended that resolution of this uncertainty be a priority item for future effort.

The degree of stabilization of the sensor package in both pointing and tracking mode appears adequate when considered in terms of its effect on resolution of the individual mine. If the "snapshot" mode is used, the settling time of the sensor servos from snapshot to snapshot appears adequate in a preliminary assessment. The RPV has considerable growth potential in payload weight and space available in the event changes specifically oriented towards minefield detection are deemed desirable.

The survivability of the RPV system as currently configured appears to be reasonably well established and compatible with the minefield detection mission. Inasmuch as the RPV in minefield detection missions is not expected to be required to penetrate more than approximately 35 km beyond FEBA (forward edge of battle area) for scenarios 1 and 4, only limited air defenses are expected to be employed against it (see Figure 1) for these scenarios. A lesser exposure to air defense is expected for scenarios 2 and 3.

The RPV sortie rate of three per twelve hour period per section together with the endurance and speed capability of the RPV appears compatible with the response times needed in connection with the Soviet minefield scenarios.

The large range of viewing angles made possible by the RPV hemispherical arrangement for sensor location allows flexibility for RPV maneuvers. The gimbal arrangement is such that viewing from nadir is not recommended. It is possible to have viewing angles 10° to 15° off nadir with satisfactory gimbal servo performance. This arrangement appears acceptable for minefield detection purposes if there is sparse, short, or no vegetation. If vegetation is 0.3 m or taller, scan angles will be limited to values less than 10° to 15° off nadir so that some provision must be made to stabilize the sensor against RPV roll.

7
DATA LINK CHARACTERISTICS

The current RPV missions require that a microwave ground based data link be used to keep track of RPV position, to send flight commands to the aircraft and to command sensor modes of use. Sensor collected data and RPV systems status is transmitted from the aircraft to the ground. The data link system is to have a high degree of immunity to countermeasures. The same overall requirements hold when RPVs are to be used for mine and minefield detection purposes although it is not yet clear whether the data link as planned will adequately fulfill the requirements of minefield detection missions.

The Modular Integrated Command and Navigation System (MICNS) is the microwave data link system slated for use with the RPV system. A tracking antenna is mounted on a remote ground terminal and maintains track of the RPV as long as there is a direct line of sight. Navigational commands and sensor commands are periodically relayed to the aircraft. RPV status is sent to the ground on the down links. Data rate is low, and narrow band signals can be used on these links. When search is in progress or a target has been acquired, video is also transmitted from the RPV to the ground. Consequently, the downlink bandwidth must be wide to accommodate the video signal from the TV sensor.

Low altitude RPV operation has the unfortunate effect of forcing the ground based data link antenna to track at low elevation angles. The effect is unfortunate because multipath reflection, i.e., the reflection of microwave signals from the ground near the antenna causes the amplitude and phase of the signal received at the tracking antenna to vary significantly from the amplitude and phase of the direct signal. Multipath reflection from the ground surrounding the antenna is particularly bad at low elevation tracking angles. Signal magnitude can be reduced essentially to below noise level or

increased theoretically to a maximum of twice the direct signal value. Tracking errors of a degree or more are not uncommon and can occur with either amplitude or phase controlled tracking systems. It is expected that the low angle tracking problem is being addressed during the course of MICNS development since other RPV missions besides the minefield detection mission are likely to share this problem. The problem is a common one and has received considerable attention over the years.

Another unfortunate effect of the low altitude requirement is terrain masking of the line of sight (LOS). Table 2 lists minimum altitude for electronic line of sight as a function of range from the remote ground terminal (RGT) of the data link system. In situations where terrain masking is severe or where the Soviet minefields are located in the more distant portions of scenario 1 it may be advantageous to use a data link relay. This relay could be mounted in an RPV which hovers near the RPV ground control station at an altitude sufficient to insure a direct line of sight to the RPV whose mission is minefield detection.

The television system's video bandwidth is assumed to be the same as required for commercial television. Allowing some bandwidth for control signals, this bandwidth is 6 MHz. The important factor is whether or not resolution needed for minefield detection is degraded within the data link system. A bandwidth compression technique or signal coding technique used in data link transmission may be designed to discard some of the information gathered by the sensor depending on the target sizes and on the resolution required for an operator's display. Whether or not such degradation sufficient to affect minefield detection occurs in the MICNS should be investigated as a matter of priority. Minefield imagery has been provided to MERADCOM for retransmittal to the data link contractor for an initial determination as to whether data link characteristics will affect minefield detection performance.

TABLE 2
MINIMUM ALTITUDE IN METERS FOR ELECTRONIC LINE OF SIGHT
RANGE FROM RGT (REMOTE GROUND TERMINAL) IN km

Site-to-Mask (Mils)	1 km	5 km	10 km	20 km	40 km
5	5	25	50	100	200
10	10	50	100	200	400
20	20	100	200	400	800
30	30	150	300	600	1200
100	100	500	1000	2000	4000
200	200	1000	2000	4000	8000

8
MAN/MACHINE INTERFACE

As presently organized and manned, the RPV section has a sensor operator and RPV operator who view the TV type sensor display and control the sensor view angle, field of view, stabilization modes and flight modes. Normally for target acquisition the sensors look forward or to the side and depression angles are generally substantially less than one radian. For minefield detection, with its emphasis on resolution and sensory access, it is desirable for the sensor view angle to be near nadir. When the sensor is near nadir the imagery displayed appears to move essentially in accordance with the RPV ground track. This situation leads to several questions - (1) Are the sensors effective in this mode and (2) Assuming sensor operation is satisfactory, can the human RPV or sensor operator effectively detect mines or minefields?

The first question has been discussed in connection with the effect of RPV speed on sensor and man/machine performance in Section 6. Two basic sensor modes are suggested, continuous motion mode and "snapshot" mode. As currently configured the TV camera imagery quality will be seriously degraded due to relative motion of the sensor with respect to the ground in the continuous mode but is expected to be of satisfactory quality for the "snapshot" mode. Full FLIR information is not available at this time. It is our current understanding that the FLIR also will be satisfactory in the "snapshot" mode and may be satisfactory in the continuous mode, contingent upon the particular design chosen.

The effect of these modes at the man/machine interface on the ability of the RPV or sensor operator to detect Soviet mines or minefields is uncertain at present. Experiments using actual minefield imagery in a simulated RPV environment to ascertain and define RPV or sensor operator capability to detect Soviet mines and minefields have been designed and proposed to MERADCOM for future effort.

9
COMMAND, CONTROL AND COMMUNICATIONS

The RPV platoon is organic to the target acquisition battery of the division artillery and functions under the staff supervision of the division artillery S-3. The platoon will consist of a headquarters section and four RPV sections. Each RPV section will nominally have five air vehicles, a ground control station and a launch and recovery capability. Normally, one RPV section will be placed in support of each committed maneuver brigade (i.e., supported unit) and one in general support of the division.

The platoon leader commands those sections retained under division artillery control. In addition to acting as the advisor on RPV employment to the division artillery commander, he is responsible for ensuring that the operational sections are trained, and monitors logistical support (to include organizational maintenance) and administrative support.

The section leader commands the individual operational section. He coordinates operations and training and logistical and administrative support with the platoon leader and the controlling unit commander/staff.

The platoon leader retains control of the operational sections until they deploy in support of a divisional unit. Upon deployment, operational control of a section is assumed by the supported unit commander.

The RPV section leader advises the supported unit commander and his staff on RPV technical aspects to include air vehicle and sensor capabilities, weather contingencies and suitability of flight routes.

When the RPV section is supporting a maneuver brigade it will normally operate in the Brigade Radio Intelligence Net, the Field Artillery Battalion Command Radio Net, and the DS Field Artillery Battalion Operations/Fire Radio Net. When the tactical situation

and distances permit, wire communications will be established to the direct support field artillery battalion's switchboard, and TACFIRE set, or to the maneuver brigade switchboard.

When the RPV section is supporting the division the communications requirements for the Division Support Section are similar to those cited for the maneuver brigade. Wire is the preferred mode of communications when distance and the tactical situation permit its installation. Communications will be established as directed by division artillery. The RPV section will normally operate in the Division Intelligence Net, the Division Artillery Command Net and the Division Artillery Target Acquisition Battery Command/Intelligence Net.

Since the RPV section supporting the maneuver brigade is directly tied to it organizationally, in command structure and through its communication nets; its responsiveness will be high and its response time low.

10
FLIGHT REGIMES

This section presents a consolidation of various factors limiting the flight regimes where minefield detection is possible. Considering vertical flight regimes, sensor resolution at the narrowest field of view (2.7°) limits maximum altitude above ground to approximately 1860 m (see Sensor Characteristics). A minimum altitude limit is imposed by the electronic line-of-sight requirement of the data link (see Table 2). Between these extremes, the weather may impose additional limitations (see Figure 8).

Analysis results indicate that infrared scanners, FLIRS, and television cameras must be operated at low altitudes if these sensors are to be able to detect mines and minefields. The chief driver for this requirement is the prevalence of cloud cover, particularly if the area of concern is West Germany. On clear days or in areas where cloud cover is at high altitudes or seldom occurs, the driving function limiting flight altitude is sensor resolution capability. This latter altitude limit is generally higher than the limits imposed by cloud cover over Germany. Figure 15 illustrates cloud ceiling values over Bayreuth as well as the maximum altitude at which a television camera can be flown so that there are at least two scan lines across a mine. This figure clearly shows that the wide FOV must be used most of the time if the sensor is to be below the cloud cover. The effect of several typical elevation tracking angles and obstacle clearance angles (mask) which determine electronic line of sight are also shown in Figure 15.

Point and areal coverage typically is within RPV endurance limitations and is separately discussed in Section 11.

Tracker limitations can also impose restrictions on permissible flight regimes. Assume, for example, that the RGT (remote ground

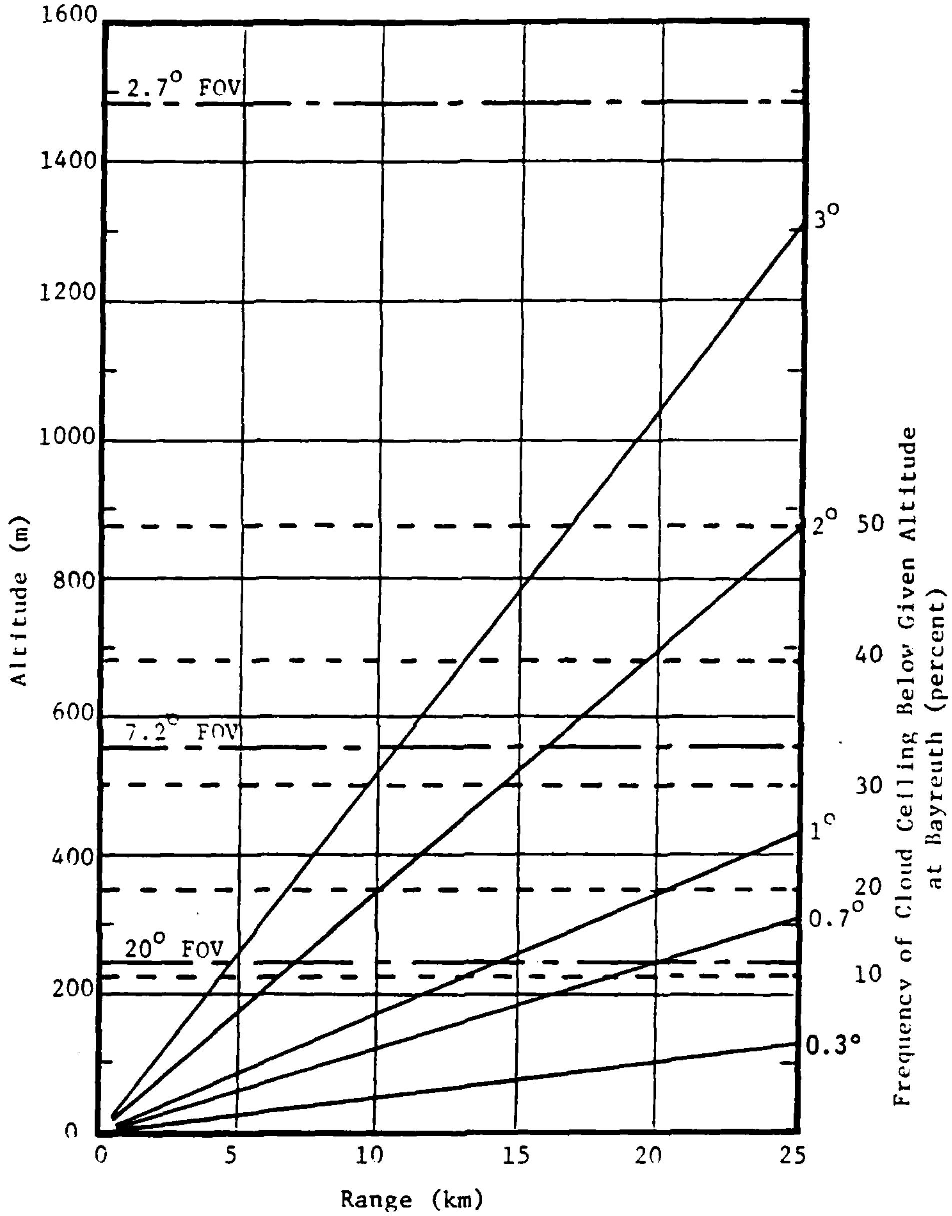
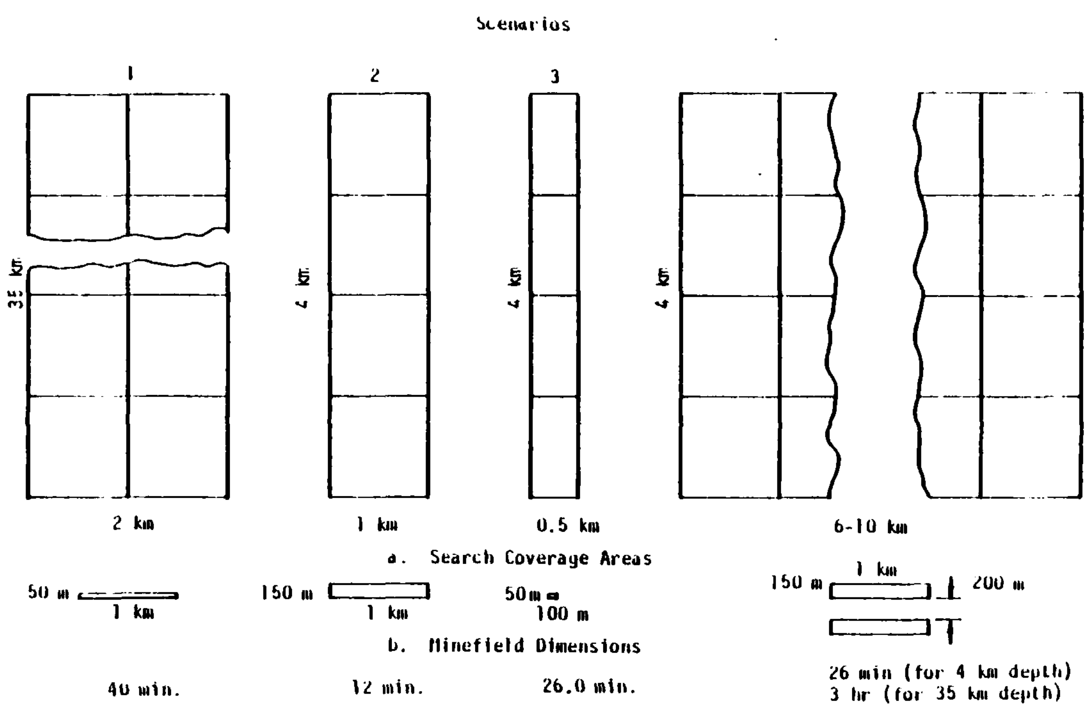


Figure 15. Elevation Tracking Angle and Obstacle Clearance. 70 m swath width and 2 lines/mine for the three FOVs.

terminal) is located reasonably near the Ground Control Station as in Figure 1. When searching for hasty minefield blocking withdrawal (Scenario 3), tracking angle can range from as low as 1.5° when the minefield is at one side of the brigade front and the tracker at the other (approximately a 10 km range) to directly overhead. If the system is not designed to track an RPV which is directly overhead, there will be a circular area surrounding the remote ground terminal in which it will not be possible to search for minefields. The radius of this area is given by the RPV altitude divided by the tangent of the maximum tracker elevation angle. If this angle is 60° and the RPV altitude is 1500 m, the circle radius is 866 m; at an altitude of 250 m, the radius is 144 m.

Minefields in Scenarios 1 and 4 will be located approximately 5 to 45 km from the tracker. At 5 km, elevation tracking angles will seldom be below 3°, even if the RPV is only at 250 m altitude (Figure 15). Under such circumstances, the RPV will be below cloud ceilings about 90% of the time. If a minefield is 45 km from the tracker and the RPV is at 250 m, the tracker elevation angle will be only 0.3°. Any obstacle in between the tracker and the minefield which exceeds the 0.3° line on Figure 15 will block the LOS. If weather conditions permit, it is clearly desirable to fly at the higher altitudes so that LOS blockage cannot occur. (Atmospheric refraction will cause the propagation paths or obstacles clearance lines to be lifted slightly above the lines which are plotted in Figure 16, but the effect at these short ranges is small.) Another conclusion which may be drawn is that the remote ground terminal should be placed as high as possible on the local terrain.



c. Typical Minefield Search Times. Search conducted normal to minefield orientation. RPV speed, 140 km/h. Search times include typical flight times to search area.

Figure 16. Minefield Search Times

Flight time for a single 4 km, 70 m swath width pass is 1.7 min.

11
POINT AND AREAL COVERAGE

The RPV system has capability for both target acquisition/designation and areal reconnaissance [1]. Generally these capabilities can be associated with point and areal coverage. Both coverages have applicability in connection with minefield detection. Response times for point coverage can be represented as the time required to launch and fly the RPV to the point where minefield detection coverage is desired. Assuming an air vehicle is available ready for launch for such a mission then response time can be closely approximated by the RPV flight time to the desired point. For the scenarios of interest for minefield detection and using the minefield relationships with respect to the FEBA and the RPV ground control station location shown in Figure 1 flight time typically is 40 min for Scenario 1. For Scenario 2, it is 12 min and for Scenario 3 it is 26 min. Scenario 4 ranges from 26 min to 3 hrs dependent on depth of coverage.

For areal coverage (reconnaissance) we may consider three general categories of missions; area reconnaissance, specific reconnaissance and route reconnaissance. Minefield detection may be associated with each of these categories. Within the limitations of our minefield detection scenarios, the first category, area reconnaissance, is the broadest of the three categories. An RPV section might typically provide area reconnaissance to detect Soviet minefields over a brigade front of 6 to 10 km to a depth of 4 km beyond FEBA. Assuming a swath width of 70 m brigade minefield detection area coverage elapsed time could range from 11 min to 6.5 h. Such coverage could typically be required in connection with Scenario 4. This particular scenario imposes much less stringent search time constraints than the other scenarios. Figure 16 shows typical search areas for the Soviet minefield scenarios. It also presents typical minefield search times for these scenarios. These typical search times are based on an RPV

ground speed of 140 km/h and search conducted in a direction normal to the expected orientation of the minefield. These times include typical flight times in the search area. It should be noted that the typical search times are generally quite modest when compared to RPV endurance.

Scenarios 1 and 2 could be considered as typical examples where specific reconnaissance is required. Search time values for these scenarios can range from 12 min to 1.5 h of RPV flight for Scenario 2 and from 40 min to 13 h for Scenario 1.

Scenario 3 is representative of route reconnaissance. Search time values for this scenario can range from 4.0 min to 21.0 min.

The range of search times presented represent variation of RPV flight time required for complete coverage from the extreme condition where top RPV speed is used and search paths are conducted in the most favorable orientation to the other extreme where lowest RPV speed is used and search paths are conducted in the least favorable orientation. All search times include appropriate values for the flight time required to reach the search area from the RPV launch site. It should be noted that the tracker can impose limitations on coverage. This subject is discussed in Section 7.

12
POSSIBLE NEXT GENERATION SENSOR SYSTEM

An examination and assessment of the current RPV TV sensor system and the planned RPV FLIR sensor system from the standpoint of minefield detection reveals the possibility of substantial improvement. In general these improvements would not degrade performance for other missions and in some cases would substantially improve capability for them.

From an operational standpoint it would be highly desirable to improve the percentage of time wherein the RPV minefield detection system could be utilized. Further it is highly important to reduce the time during which the RPV is in flight over areas where its survivability is at risk. Finally, it would be highly desirable for the RPV minefield detection system to have a high probability of detection and a low probability of false alarm.

Considering these important operational factors, there are several technical approaches which are available to alleviate current limitations.

To increase the percentage of time when RPV mine detection capability is useful there are several attractive approaches. Foremost of these is the currently planned addition of a FLIR capability to the present RPV system. This passive IR sensor would add a nighttime capability to the current day capability of the TV sensor. The portion of time when sufficient thermal contrast exists for passive IR minefield detection is discussed in Section 3.

Although the addition of a passive infrared sensor capability to the RPV sensor package improves the percent of time useful compared to a TV system because the passive system can sometimes be used at night, the passive IR sensor is still limited to periods when sufficient thermal contrast exists between the mines and background. Recent investigations at ERIM have established that the PM-60 and TM-46

Soviet mines give strong specular returns when illuminated by a 10.6 μm laser beam [7]. These returns are relatively independent of the thermal conditions at the mine and its immediate surrounding. The beam of the specular return is but a few degrees wide and accordingly the return is sensitive to the angle of repose of the mine with respect to the illumination beam. Thus mine detectability is a function of terrain irregularity. It should be noted that signal-to-clutter ratios of 10^2 or more are not unusual for such a system and that detection of all individual mines is not a requirement for detection of a minefield. Further the strong signal-to-clutter ratio lends itself to automated operator assist or target recognition schemes. Based on these considerations active IR or a combination of passive and active IR seems worthy of detailed exploration and demonstration as a means for improving the percentage of time when the minefield detection system can be utilized.

Another possibility for improving percentage of time useful for minefield detection is to operate the RPV at lower altitude regimes where cloud obscuration effects are diminished. This effect is vividly illustrated by Figure 8. This approach has limitations such as performance requirements of the data link. The data link requires a clear electronic line of sight to the RPV. Figure 15 lists the minimum altitude for electronic line-of-sight as a function of the angle between the RGT site and the mask; and the range of the RPV from the remote ground terminal. It is apparent that data link performance severely constrains RPV flight at lower altitudes and that considerable attention should be paid to site selection for the RGT to minimize this constraint.

Another way to improve operational effectiveness is to decrease the exposure time during which the RPV is in flight over areas where its survivability is at risk by reducing the minefield search time. A possible means for realizing reduced search time is the use of a wider swath width. The wider swath width in turn implies a higher

TV or FLIR data rate with its attendant reflections on the data link. One possible solution to this difficulty would be the use of line scanner techniques which would allow significantly lower data rates than the TV or FLIR currently planned for the RPV. Another approach would involve on-board preprocessing of sensor outputs to reduce effective data rates to a degree amenable to the data link without significant degradation of essential minefield detection information.

Operational effectiveness can also be enhanced for minefield detection systems by improving the probability of detection and reducing the probability of false alarm. There are at least three means for accomplishing this objective, all of which are applicable to the RPV system. First, it is possible to decrease probability of false alarm (P_{FA}) through improved resolution and sensitivity of the sensor system. For the RPV TV and FLIR sensors improved resolution while maintaining coverage implies higher data rates. Again line scanner techniques or on-board preprocessing of the sensor data appear to be possible approaches to attainment of improved resolution. Considering improvement of sensor sensitivity, minor improvements may be expected but current sensors approach theoretical capability limitations. Secondly, it is possible to achieve improved P_D and lowered P_{FA} through the use of more distinctive target signatures. As previously discussed, active IR mine signatures at 10.6 μm are quite distinctive and offer possibility for lowering of P_{FA}. It should be noted that the probability of detection for this approach may be rather low. However, there will be a high confidence associated with mines detected using active IR at 10.6 μm. Again, the combination of active and passive IR appears to be complementary and attractive for minefield detection. A third approach to improve P_D and lower P_{FA} involves a more effective man/machine interface. It appears possible to provide considerable assistance to the sensor operators and the RPV operators in the detection of minefields through various automatic enhancement techniques. For

example, all detections involving targets larger than an individual Soviet mine could be rejected; all detections having specified spatial arrangements peculiar to Soviet minefields could be enhanced. Finally, it seems possible through extension of these techniques, that Soviet minefields could be recognized automatically together with initiation of search patterns intended to completely define and precisely locate them.

13
FINDINGS AND RECOMMENDATIONS

13.1 GENERAL

Finding 1. The RPV system, as presently configured and planned, will have a significant and operationally useful capability to detect Soviet minefields in the West German theater. The minefield detection capability of the RPV should be explored for other theaters of interest. The RPV system, as presently configured, uses a television sensor and consequently is limited to daytime use, perhaps on the order of eight hours or less each day, particularly in winter. However, the RPV system does not restrict night use since the system is designed to accommodate night launches and recovery. Acquisition of a FLIR sensor as is already planned will enable the Army to increase the usable operation time to nights as well as days. It is expected that FLIRs can be used to detect Soviet mines and minefields since the FLIR resolution capability will be similar to that of the television system. The FOVs for the FLIR are assumed to be the same as the television system.

Recommendation 1. Since the FLIR is currently under development for the RPV application, the various FLIR approaches should be reviewed for compatibility and upgrading potential with respect to the minefield detection mission.

13.2 MINES AND MINEFIELDS

Finding 2. Preliminary tests indicate sufficient thermal and optical contrast can exist between mines and background that minefield detection is possible under proper circumstances [8, 9].

Recommendation 2. Experiments and data acquisition efforts should be designed and implemented to delineate range and frequency of occurrence of target/background contrast levels to be expected

for current planned and potential sensor complements for the RPV. These efforts should encompass a sufficient time span so that the effects on contrast of seasonal and vegetational variations can be appropriately assessed. The objective of this effort is to develop an information base sufficient to determine the percentage of time conditions exist at the minefield which would allow its detection. The current effort to acquire mine and minefield data in a simulated West German environment at array II and supplemental arrays in Oregon should be continued. The appropriate portions of RPV Phase 1 and 2 of Plan III [10] should be implemented. In addition, consideration should be given to development of target/background contrast data for other theaters.

Finding 3. Preliminary tests indicate that Soviet PM-60 and TM-46 mines give strong specular returns compared to background when illuminated at 10.6 μm. A similar but lesser effect exists at 1.06 μm [7].

Recommendation 3. Since the active IR depends on a different signature effect, it offers potential for expanding the percent of time conditions at the minefield exist which would allow its detection. It is recommended that this approach be investigated sufficient to allow substantiated judgments to be made regarding its use in conjunction with the RPV system. The effort delineated in New Concepts, Subsection 1, Phase 1 of Plan III appropriate to the RPV system should be initiated with this objective.

13.3 SENSORS

Finding 4. At least two increments of the sensors resolution element must cover a mine in order for it to be detected. Both the TV sensor and the planned FLIR sensor are capable of providing the requisite resolution under certain RPV flight regimes. Maximum swath width of 70 m and RPV operating altitude of 1860 m for minefield detection are limited by resolution capability of the sensors.

Recommendation 4. Possibilities for increasing sensor resolution capabilities should be explored sufficient to provide a basis for decision regarding the desirability of upgrading sensor resolution. This effort should include the focal plane array study suggested as Phase I, Task 1.6 of the Active IR effort. Since improved resolution affects data rate with possible attendant reflections on the data link design, the resolution study should consider these implications and means for minimizing their effect. The use of line scanner techniques or onboard preprocessors, as suggested in Section 11, as a means for allowing significantly lower data rates should be included in the study.

Finding 5. With the TV sensor, minefield detection is limited to conditions of favorable contrast during daylight hours. The use of the planned FLIR will generally allow more favorable mine/ background contrast and both day and night operation. Other sensor approaches and combinations of sensors offer the possibility of further improvement in percent of time the sensor system is useful for minefield detection.

Recommendation 5. Active TV should be explored as a means for extending percent of time useful for the TV sensor. The planned FLIR approaches considered for the RPV should be scrutinized in detail to ascertain their suitability for the minefield detection mission. If modifications are found to be necessary, they should be made as early as possible in the development cycle. Alternative sensor approaches and combinations of sensors should be explored in detail with the objective of improving percent of time useful and probability of detection and decreasing probability of false alarm. To implement this recommendation, the appropriate portions of RPV Phases 1 and 2 effort, together with active IR effort of Plan III [10], should be implemented.

Finding 6. RPV flight motion along the ground track will tend to degrade TV imagery and may degrade FLIR imagery dependent on

design approach chosen. This effect increases as viewing angles approach nadir. RPV flight motion may also affect man/machine interface performance inasmuch as it may degrade sensor operator ability to detect minefields.

Recommendation 6. Effects of RPV motion along the flight path on sensor imagery and minefield detection performance should be thoroughly investigated together with the development of approaches to reduce effects of RPV flight motion to acceptable levels. As a minimum, the "snapshot" mode discussed in Section 4 should be thoroughly investigated and demonstrated. Ancillary effects such as effect on RPV sensor operator ability to detect mines should also be made a part of this investigation. The recommended effort is generally described in the appropriate portions of RPV Phase 1, 2 and 3 effort of Plan III.

13.4 OBSCURATIONAL FACTORS

Finding 7. The major obscuration factors for the RPV mission payload system affecting sensory access are weather, terrain, vegetation and atmospheric attenuation. These factors are characteristic of and generally unique to the theater of operations.

Recommendation 7. The ongoing and planned effort to delineate obscuration factors characteristic of the West German theater should be pursued. Recommended effort is generally described in the various sections of Plan III. In addition, consideration should be given to the development of obscurational data for other potential theaters.

Finding 8. A near-nadir viewing angle is desirable for several reasons, each of which reflects importantly in terms of RPV effectiveness for minefield detection. The obscurational effects of vegetation and atmospheric attenuation tend to be minimized at near-nadir viewing angles. For a given resolution, permissible flight altitude is maximized at nadir. The unique signature effects of active IR

are most apparent at and near nadir. If a line scanner sensor is deemed desirable, then nadir or near-nadir viewing is advantageous.

Recommendation 8. The limitations of the present RPV sensor package in the near-nadir region should be more adequately explored and defined. The effects of these limitations on mine detection performance should be assessed. If substantial performance penalties are caused by limitations on near-nadir viewing angles or stabilization system performance, alternative approaches should be explored. This effort is generally described in Phase 1 and 2 of RPV Plan III.

13.5 RPV CHARACTERISTICS

Finding 9. The range, endurance, service ceiling, sortie rate, survivability, the degree of pointing and tracking stabilization, viewing angles and payload growth potential appear adequate for the minefield detection mission. RPV flight speeds tend to degrade TV sensor imagery (see Finding 6).

Recommendation 9. The preliminary findings regarding the above should be further verified in accordance with the RPV Phases 1 through 4 of RPV Plan III.

13.6 DATA LINK CHARACTERISTICS

Finding 10. Data link electronic line-of-sight requirements are a limiting factor in connection with low altitude minefield detection missions.

Recommendation 10. Since proper siting of the remote ground terminal (RGT) can have a major impact on electronic line-of-sight, it is recommended that means for obtaining advantageous siting be carefully assessed. In particular, the potential of automated terrain analysis currently being developed by U.S. Army Engineer Topographic Laboatories should be explored for this application. Effort to implement this recommendation is included as part of Phases 1, 2 and 3 of RPV Plan III.

Finding 11. The characteristics of the data link may affect the fidelity of transmission of minefield detection sensor outputs from the RPV to the ground.

Recommendation 11. Effects of data link on transmission of sensor imagery should be thoroughly investigated. In the event that imagery is seriously deteriorated by the data link, approaches to minimize these effects should be developed. Possible approaches are the use of on-board pre-processing and the use of line-scanner techniques to reduce imagery bandwidth requirements. An exploration of data link effects is included as part of Phases 1, 2 and 3 of RPV Plan III.

13.7 MAN/MACHINE INTERFACE

Finding 12. With near-nadir viewing, the effect of RPV motion along its flight path may affect the ability of the sensor or RPV operator to detect minefields (see Finding 6).

Recommendation 12. Experimentation and analysis should be undertaken to ascertain whether sensor or RPV operator performance is degraded by RPV motion along its flight track. Both continuous and "snapshot" modes of sensor operation should be considered. ERIM has proposed an experiment using Array 1 imagery to investigate RPV motion effects on sensor and RPV operator performance. This effort should be funded as a priority effort since the utility of the RPV system as a minefield detection system may hinge on this particular aspect. Findings from this experiment should serve as a guide for further determinations regarding RPV motion effects. It should be noted that in the event that operator performance is seriously degraded by RPV motion, there are techniques in the developmental stage capable of providing operator assist or possibly automatic recognition of minefields.

13.8 COMMAND, CONTROL AND COMMUNICATION

Finding 13. A preliminary assessment of command, control and communication for the RPV system indicates that good and direct linkages exist from the RPV sections to brigade maneuver elements directly concerned with enemy minefields. Similar linkages exist to the division. RPV sections should be capable of responding in a timely fashion for scenarios of interest for minefield detection.

Recommendation 13. The initial findings should be verified by a more comprehensive examination of command, control and communication. Such effort is included in recommended Phases 1, 2 and 3 of RPV Plan III and subsection 5, Study of C3I Implications on Minefield Detection Systems, of New Concepts/Analysis/Data Base, Plan III.

13.9 FLIGHT REGIMES

Finding 14. There are distinct limitations on flight regimes where minefield detection missions are possible. Using TV or the planned FLIR sensors, the maximum altitude above ground level wherein minefield detection is possible is approximately 1860 m. Actual flights may be constrained to altitudes substantially less than the maximum due to obscurational factors. The range of fields of view (FOV) available allows operation with maximum swath width down to approximately 250 m. Minimum flight altitudes are limited by electronic line-of-sight considerations in connection with the data link. The RPV section generally is capable of providing both point and areal coverage over the frontage normally covered by the brigade which it supports. It should be noted that the RPV tracker can impose limitations on coverage.

Recommendation 14. These initial findings should be verified by a more comprehensive assessment of flight regimes. Means for possible expansion of permissible flight regimes which will enhance operation usefulness should also be explored.

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